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## STRUCTURAL WELDMENT INSPECTION

by John L. Beaton and Paul G. Jonas

STRUCTURAL DIVISION

*{Discussion open until December 1, 1953}*

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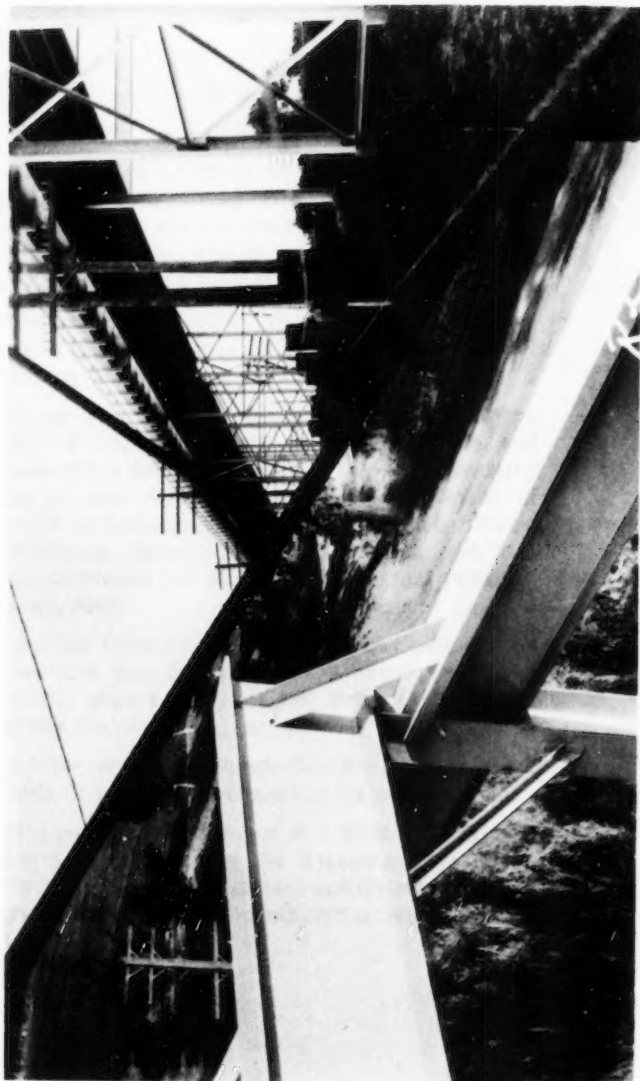
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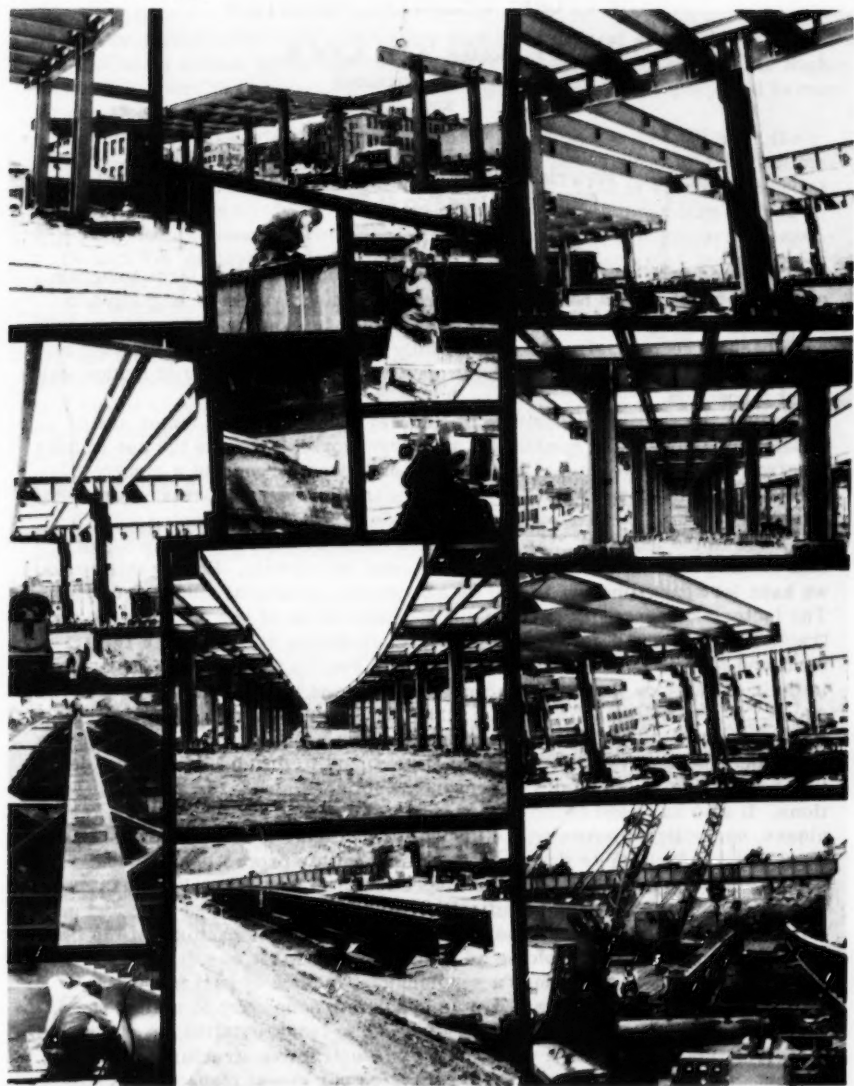


BRADLEY OVERHEAD LOCATED NEAR  
MERCED, CALIFORNIA. CONSTRUCTED IN 1935.  
ALL SECONDARY CONNECTIONS MADE BY WELDING WITH BARE ELECTRODE

FROM THIS IN 1935 --



-- TO THIS IN 1952.



WELDED CONSTRUCTION ALONG BAYSHORE FREEWAY  
NEAR SAN FRANCISCO

## STRUCTURAL WELDMENT INSPECTION

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The rapid progress of the welding industry coupled with a large program of welded construction has required the California Division of Highways to pause and restudy its fabrication inspection and testing methods. The results have been to reemphasize the need of fully qualified visual inspection but at the same time has emphasized the proper place of radiography in bridge weldment inspection.

In 1935 the California Division of Highways made its first major use of welding as a connecting medium in its bridge work. This was the use of bare electrodes for the welding of all minor connections throughout a structural steel trestle, Bradley Overhead, located near Merced, California. During the intervening years further use has been made of welding in keeping with the progress of the industry. However, it has not been until the last two years that welding here in California has been used extensively. During this period we have let approximately 15,000 tons of welded structural steel to contract. The factors influencing this trend and the fabrication of one of our large contracts have been well covered by Mr. L. C. Hollister of our Bridge Department and Mr. R. W. Binder of the Bethlehem Pacific Coast Steel Corporation in their articles on the Division Street Interchange in the September, 1952 issue of CIVIL ENGINEERING.

So as to take advantage of the economies of a rapidly progressing industry it has been necessary for our Bridge Department to project its designs during this period beyond the limits of presently published standards and specifications. It also has been necessary to readjust some of our procedures, techniques, and policies covering the inspection and testing of such work. It is these latter adjustments that will be covered in this paper.

Over the past several years the inspection of structural welding has more or less standardized to the qualification of the welders, procedures, and materials; followed with close supervision by a qualified inspector. At the beginning of our major use of welding as a joining material it was decided that in addition to the usual procedure a supplemental method of post inspection should be used. This, it was felt, was absolutely necessary to satisfy the exacting safety requirements necessary for public transportation. A study was, therefore, made of all tried methods of non-destructive structural weldment inspection. As the result of this investigation our visual inspection is supplemented by penetrant dye, trepanning, and hardness testing during fabrication followed by radiographic inspection of the completed weldment.

Preheat where required is controlled through the use of Tempilstiks and surface contact pyrometers. When we have reason to be concerned over the metallurgical structure we make special investigations through the use of

micro and macro photographs. For your information we will outline in more detail our procedure in supervision of weldment fabrication, starting with the specifications as prepared by our Bridge Department.

#### Specifications

The specifications which control our welded structural steel fabrication are the latest edition of the American Welding Society Specifications for Highway and Railway Bridges supplemented by Special Provisions prepared by our Bridge Department.

These Special Provisions have changed from project to project over the past two years as experience has developed. The latest specification, but by no means considered to be the last, is given below. This is a briefed copy as only those features essential to welded construction have been listed. You will note from a review of these specifications that they are concerned essentially with the requirements of metallurgy especially insofar as preheat requirements are concerned. It was considered that preheat requirements for good fabrication would automatically be assumed by the fabricator. In most cases, this is true. However, due to the fact that the advantages of preheat are not always apparent, while the original cost of preheat is very apparent there is a tendency at times to eliminate preheat from consideration. Actually it is our experience where the thicker materials (above 1 ) are being welded, especially in a weldment involving also thin sections, that the original use of preheat would have more than paid for itself. In addition it would have eliminated the delays and disfigurements caused by the necessary "pickup". So that everyone will have a common base on which to bid, it is now being considered that the inclusion in our Special Provisions of a preheat requirement up to 400° F. should be made for use during the fabrication of heavy sections.

#### SPECIAL PROVISIONS

Steel construction shall conform to the requirements of Section 35 of the Standard Specifications and the following provisions.

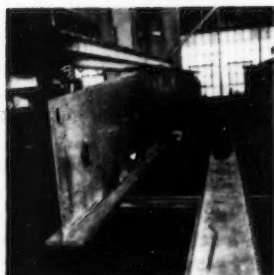
In addition to the requirements of Chapter II, article (a), of the above section, all plates over 1 inch in thickness used for making up the welded plate girder, cap and column sections shall be of steel made by either or both of the following processes: open hearth or electric furnace. The steel shall conform to the following chemical and physical requirements:

#### CHEMICAL REQUIREMENTS - LADLE ANALYSIS

Carbon, max., percent	0.25
Manganese, percent	1.15 max
Phosphorus, max., percent	0.04
Sulphur, max., percent	0.05
Silicon, percent	0.15 to 0.30

#### PHYSICAL REQUIREMENTS

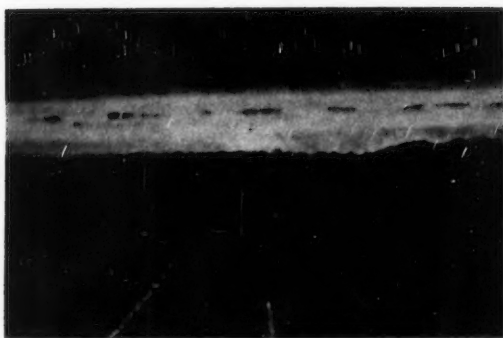
Tensile strength psi	58,000 to 75,000
Yield point, min., psi	32,000
Elongation in 8 in., min., %	21
Elongation in 2 in., min., %	23



Cap girder flanges welded and ready for bearing brackets and stiffeners. Welding was done by the automatic shield arc process, preheated to 300° F in welding area.



Automatic welding of a girder with preheating torch ahead of welding. There is also a heating torch in back of welding machine to control cooling.



A defective fillet weld checked with penetrant dye showing surface defects. The white surface of the weld is the developer and the dark lines in the middle of the weld are caused by the penetrant dye bleeding out of the defects onto the white surface.

For material over 3/4 in. to 2-1/2 in. inclusive in thickness, a deduction from the percentage of elongation in 8 in. specified of 0.25 percent shall be made for each increase of 1/32 in. of the specified thickness of 3/4 in. to a minimum of 19 percent.

The bending properties, as represented by test specimens, and the number of tests shall conform to the requirements specified for structural steel, A.S.T.M. Specification A7-49T.

All welding of flange plates to web plates shall be performed by either the submerged arc process or with low hydrogen electrodes, with the exception that when welding material less than one inch in thickness to other material less than one inch in thickness electrodes conforming to Section 4, article 401, of the specifications of the American Welding Society may be used in lieu of low hydrogen electrodes.

Low hydrogen electrodes shall conform to the requirements of the Military Specifications for Electrodes (Mineral Covered, Low Hydrogen), for Welding Medium Alloy Steels, MIL-E-986 (ships), Grade 180, dated November 1, 1949. Care shall be exercised to prevent the absorption of moisture by the low hydrogen coatings. Electrodes which have been removed from their moisture-proof containers for periods of more than 12 hours shall be restored by drying for 2 hours or more at a temperature of 300° F. in an approved furnace.

The welding technique to be followed in welding built-up members of heavy sections shall be qualified by test before being admitted for use.

In lieu of the provisions of Section 6, article 604, (f) and (g), of the American Welding Society concerning preheating and postheating when welding built-up members of heavy section, the following provisions shall apply: No preheating or postheating will be required where the component parts are 2 inches or less in thickness. In welding members where the component parts are more than 2 inches in thickness the temperatures of contiguous areas about a welding operation shall be substantially equal and not less than 100° F. No welding will be permitted when the ambient temperature is below 20° F.

All welding shall be performed in such a manner that the Brinell hardness of the heat-affected zone does not exceed 190.

All welds shall be subject to non-destructive testing by the Engineer. Such non-destructive testing will be performed without cost to the Contractor.

Fabrication tolerances for built-up girders and caps shall not be more than 50% greater than the A.I.S.C. tolerances for WF shapes and the tolerances for built-up columns shall not be more than 50% greater than the A.I.S.C. tolerances for WF shapes specified as columns.

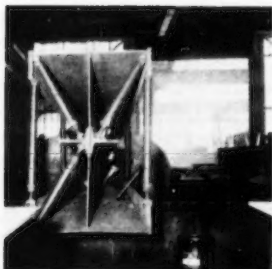
#### Materials

Following standard A.S.T.M. procedure base metal is tested and inspected at the mill.

When considered necessary, welding electrode is sampled in the shop and tested in the Sacramento Laboratory. It is routine to check all welding rod by the fillet weld test and all low hydrogen electrodes additionally for moisture content. Complete A.S.T.M. tests are only made when it is apparent that the classification of the rod is not correct. We seldom find deviation from the manufacturers ratings. We do find that care must be exercised insofar as the low hydrogen electrodes are concerned, since it must be classified under the military specifications, MIL-E-986.



Composite action  
lugs 1"x4"x10" were  
also manual welded  
with a class E6012  
electrode as well  
as semi-automatic.



Showing the welding  
of a column after  
line up jacks are  
in place and tack  
welded. Two welders  
are welding simul-  
taneously 12"  
apart and welding  
in the same di-  
rection to alleviate  
distortion and weld  
bead cracking.



This web plate was  
cut out by the oxy-  
acetylene method  
and all edges ground  
before fitting. It  
was welded by the  
automatic shielded  
arc process. These  
web plates for cap  
girders are 56'6"  
long, 5/8" thick.  
The top flange is  
1-3/4"x12", and  
bottom flange is  
1-1/4"x18".

### Qualification

Insofar as the qualification of welders for manual welding both in the shop and the field are concerned, we follow the American Welding Society qualification test. Such qualification tests are expensive however, and in our judgment are necessary only when a man is first qualified to do our work. We use the simple fillet weld break test extensively, for two reasons. We find that if a welder cannot pass this simple test it is not economical to go ahead with the complete A.W.S. qualification test. We also find it to be economical in checking the continuing skill of a manual operator.

For qualification of semi-automatic or automatic equipment operators, the procedure is slightly modified. Our work usually requires a procedure qualification so both procedure and operator are qualified at the same time. This type of welding is always run in a flat position so the welder is qualified only in this position for the welding of butt and fillet welds. The test plates are then tested to the standard A.W.S. procedure qualification requirements. We find here than an x-ray of the test plates before starting the standard tests is very helpful. If the x-ray indicates excessive defects, there is no value in completing the test. X-ray plates of this type are costing only about \$6.00. This not only saves the expense of completing the tests but also gives the results immediately. We usually use a nick break test to check the continuing skill of the operators of this type of equipment.

The prequalification of procedure for automatic welding is made by making trial runs on small sections containing material of the same sizes and shapes and under the same welding conditions to be used during the fabrication. After this trial run is made the weldment is then cut up into sections for examination. Inspection is made concerning depth of penetration, size and shape of weld bead, slag inclusion, porosity, cracks and structure of weld metal. Hardness checks also are made in the fusion zone, heat affected area, and of the unaffected parent metal.

For the welding of long sections, run over tabs are used on the end of the sections. These tabs serve two purposes. They insure continuity of the weld to the end of the member and also are cut up into sections for testing so that a true representation of the weld in the structure is observed.

### Visual Inspection

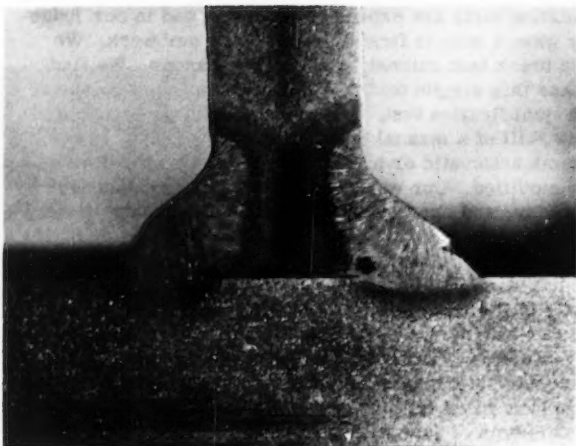
Visual inspection can be broken down to five important points.

1. The selection of the inspector
2. Prefabrication review of planned procedure and sequence
3. Inspection prior to welding
4. Inspection during welding
5. Inspection after welding

The above points are listed in their order of occurrence. It is merely coincidence that the first listed also happens to be the most important.

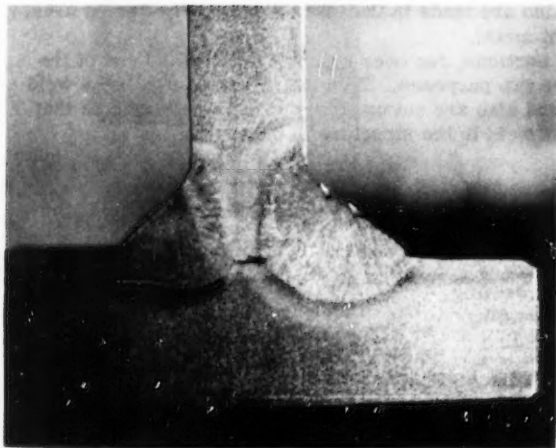
The welding inspector must not only know and understand the principles of inspection but he also must be so familiar with welding fabrication that he could actually do the job. He must be able to anticipate difficulties and possess the ability to communicate his thoughts to the shop personnel. He also must have the ability to know and understand the abilities of each welder on the work. Above all he must know and understand the causes of all defects, especially the hidden defects that can occur during welding.

Our second point is the first duty of the welding inspector when starting a new job. It is important that he sit down with the engineer and the fabricator and go over the shop drawings, discussing in general the procedures and se-



←

Welding can also be affected by the angle of the electrode in relation to the plate of fillet to be welded. So if the electrode is allowed to burn off on the weld metal and not in the crater, lack of fusion and slag inclusion at the root of the weld will result as shown.



←

Using the same method of welding as above, but the right anglation in relation to the fillet weld gives this good weld.

quences to be used during fabrication. At this time any anticipated difficulties can be discussed and the inspector can plan his work to fit the job. It is at this time that a harmonious working relationship is developed between the inspector and fabricating personnel. This step leads naturally into the third step of inspection prior to the actual welding.

In this group falls the inspection of the shop equipment for its adequacy to handle the fabrication, the checking of the base metal against the test reports, inspection of the welding electrodes, inspection of fit up and joint preparation, and proposed jigs.

The next step is the inspection during the actual welding operation. Here the inspector may have several welding operators under way at any one time. So it is necessary that he not only consider the visible occurrences but also it is necessary for him to keep his hearing alert at all times. His observation will not only cover the fusion and penetration being obtained, but also the formation of the welded bead, the burn off rate of the electrodes, and the sound of the arc. The qualified welding inspector should be able to tell from any one of these items whether or not the proper procedure is being used and also the results being obtained.

The last step or the post inspection of the welding when done alone can be misleading, but when worked into a complete program it is very valuable. The surface defects such as undercutting, overlay, major cracking and surface porosity are obvious. To the experienced inspector the size and shape of the weld can also tell the location of craters, slag inclusions and subsurface porosity. However, complete responsibility cannot be placed in even the most competent inspector for determining subsurface defects only by post inspection.

There are certain aids to visual inspection which are quite valuable. The penetrant dye method is useful not only for the detection of cracks, but also to determine the limits of subsurface defects during the repair process. The penetrant dye method is especially useful in connection with the automatic welding process. Here the welds are smooth enough to check without grinding especially for small surface defects. When the run over tab of a weld shows internal defects we grind into the metal and with the penetrant dye check for the defect and establish its limits.

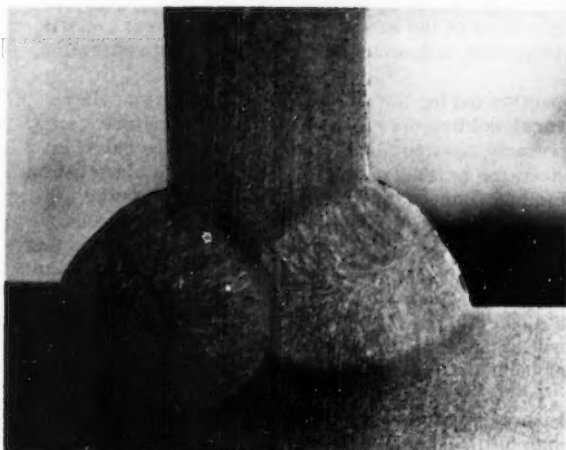
Our use of trepanning is primarily with fillet welds for the determination of penetration. We also use the trepan tool to obtain specimens for microphotographs. Our work being of heavy sections does not lend itself well to magnetic particle inspection, therefore, we do not use it.

A portable Brinell hardness machine is used in the shop and field for determining the hardness of the weld affected areas. This type of hardness testing is not as accurate as under laboratory conditions, but it does serve as a guide which we supplement with laboratory tests on tab end specimens. We have found the portable hardness tester to work out well for supervision purposes.

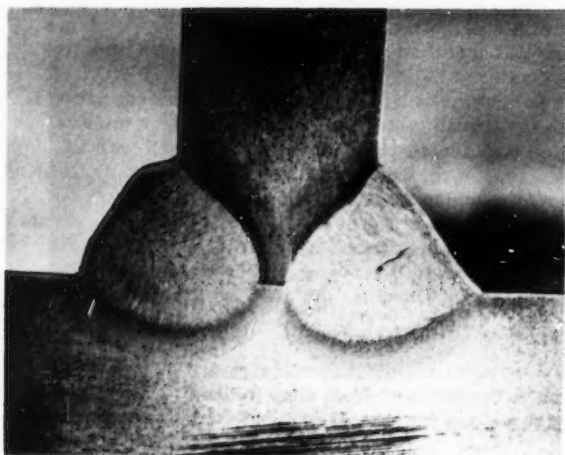
#### **Fabrication**

The details of fabrication of course vary from shop to shop. Therefore, we wish to point out in this paper and its photographs only those areas of common concern.

For automatic and semi-automatic welding, oxyacetylene cutting is used for joint preparation in most cases and also for the cutting of sections for fabrication. The cut out sections have their flame cut edges prepared by grinding prior to welding. The grinding overlaps the sides slightly so as to remove all oxidation slag, rust, and mill scale. An important point of concern in au-



Cracking of the type shown in these two pictures often occurs when the pear shape weld is made. The defect is caused when the weld is cooling down. The large center portion cools more slowly than the rest. The shrinkage of the remainder of the weld area causes a tear in the center portion.



Cracks can also be caused by impurities such as slag from an oxyacetylene cut that has not been properly cleaned. The weld metal contains a good deal of impurities and slag would exist between the grains of the weld metal in the bulgeous center.

tomatic welding is the fact that foreign matter tends to be trapped during the weld process, whereas in manual welding the objectionable substances may be removed by manipulation. If not removed, this slag inclusion would show up in the weld as a globular defect or it may cause cracking.

Manual welding requires the use of open joints during fabrication. Whereas in automatic work the joints are butted tightly together. Automatic equipment uses such high amperage that if tight fit is not obtained the electrode will burn through. Small tack welds are usually used for holding automatic work together while welding.

As stated previously, most parts fabricated into the structure are flame cut, except for small pieces which are sheared. In flame cutting on radius where stress will be involved the cuts must be smooth and free from nicks. Therefore, after cutting grinding is usually necessary to meet specifications.

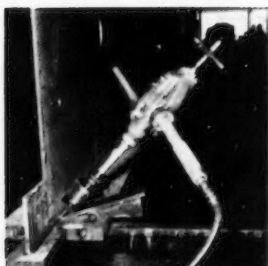
The majority of our welded structures are long heavy stringers or girders. Automatic welding lends itself well to this type of fabrication. However, care must be exercised to control warpage, distortion, and weld shrinkage cracks. Preheat up to 400° F. combined with a balanced program of control of heating and cooling will usually result in a weldment well within A.I.S.C. tolerances for structural shapes. As a secondary benefit out tests indicate that the metallurgical condition of the weld can be expected to be improved by the use of such preheat.

#### Radiographic Inspection

As previously stated it was decided approximately two years ago that radiographic inspection of our welded construction was a necessity. After this decision our next problem was when and where to radiograph. It was obvious that it was unnecessary, besides being uneconomical, to make plates showing 100% of the welding. The general policy we adopted at that time was to radiograph all butt welds of tension flanges. In addition, it was decided that if continuing defects were observed in the tension butt welds the compression butt welds would also be 100% radiographed, otherwise only one out of every four compression flange butt welds would be so pictured. This procedure we still follow. Insofar as fillet welds are concerned, our policy has undergone a change, in that we originally considered radiographing as high as 10% of this type of welding. We have now decided that once procedure has been regulated in fillet welding there is little value of continuous radiographic exposures. We, therefore, use radiography during the procedure qualification stage for fillet welds, but thereafter only if we wish to prove the presence of an already suspected defect or if there is a change in procedure. We would like to point out that an experienced radiographic technician can picture all of the defects in a butt weld. However, our experience indicates that extreme care must be taken to duplicate this fact in fillet welds especially where a relatively thin web is being welded to a very thick flange.

Insofar as our standards are concerned, we feel that an acceptable weld must be free from any form of cracking in the weld and weld area, however, it may contain slight oxide or slag inclusions or small gas pockets, providing that they are within tolerances indicated by the American Welding Society specifications. An unacceptable weld is one not meeting the requirement of acceptable; for instance, a chain of slag inclusion or porosity, poor fusion or lack of fusion, any type of crack, all require repair before being accepted. Such standards necessarily must be arbitrary. However, as the use of radiography develops it is considered that procedures can be developed which will permit a closer correlation of defects to the stresses or use of the joint.

From the viewpoint of inspection our experience has indicated that the four



← Trepanning device made for cutting 1/4" diameter cores out of fillet welds for microphotographs and also to show depth of penetration.



← A typical method of stacking butt welded flange plates for radiographic inspection.



← Radiographic film revealing defective weld due to lack of fusion at root of butt weld.



most important points to consider in the administration of radiography are:

1. Careful and experienced selection of the weld areas to be radiographed
2. Careful selection of an experienced radiographic agency
3. Careful and experienced interpretation of the radiographic film
4. Consultation with the management and shop personnel on the results of the radiographic inspection whether or not repairs are necessary

Of course the prime purpose of radiographic inspection is to determine the adequacy of the weld, however, we find several secondary benefits just as valuable. These benefits are primarily in the effect of radiography on the welding operator. Such inspection tends to induce the operator to exercise additional care. Also, by seeing the defects on the film, along with a discussion of the cause, the work habits of most welders are improved. During the past two years our radiographic work has been done by both x-ray and gamma ray with the gamma ray source being either radium or Cobalt 60. At present high energy Cobalt 60 is the most used. Our inspections usually are recorded on either 4-1/2 x17 or 3-1/2 x16 film. The work is done under Service Agreement by various commercial radiographic laboratories. The history of our costs during the past two years is interesting. In the beginning they were about \$26 per plate, this cost reflected a lack of experience on our part combined with lower sources of radiation than are now available. At the present time, our costs are averaging about \$7.50 per plate, with the lowest figure so far attained at \$2 per plate under ideal conditions.

On an overall basis radiographic inspection during the past two years has averaged about \$0.16 per ton of welded steel construction. This figure will vary of course depending on the size and design of each job. Our experience indicates that under the safety requirements of our structures, radiography is well worthwhile.

#### Conclusion

The welding of structural steel is a rapidly advancing science. Therefore, it is not ready to be tethered by completely objective specifications in all its areas of operation. However, there are certain needs which should be clarified by the development of specifications for overall use. These are:

1. A specification covering automatic and semi-automatic welding as well as manual welding.
2. A specification covering the use of preheat and heat control during fabrication, specifically for fabrication
3. A specification covering welded fabrication tolerances
4. A specification covering a weldable steel, especially covering the thicker sections

It is felt that the most important policy concerning our weld inspection is discussing the job with the fabricator before the work starts, especially covering all proposed welding procedures and sequences. We find that this leads to a harmonious cooperation between our inspection force and the fabricator, resulting in structures of which we all can be proud.



## MOSAIC SHOWING FABRICATION OF STEEL WELDMENTS

1. Completed all welded columns
2. Shop fabrication of all welded pedestrian overcrossing
3. Trepanning device for sampling fillet welds
4. The fabrication of an all welded cap girder
5. Automatic shielded arc welding head and
6. operator's station (two types of machines)
7. Welding a column web plate to the flange
8. Flange plate of a column positioned for automatic welding
9. Welder operating a semi-automatic, manual weld
10. Manual welding bearing brackets with low hydrogen welding electrode
11. A face guided bend test specimen from a welders qualification test
12. Post inspection of fillet welding in a column
13. Preheating girder for automatic shielded arc welding
14. A fillet weld test plate
15. Laying out and installing bearing brackets on cap girder for welding
16. Column web plate positioned for automatic shield arc welding
17. Fitting up a column base for welding
18. All welded column



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